Mobile Tactile Stimulation for Passive Haptic Learning of Simple Melodies

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Mobile Tactile Stimulation for Passive Haptic Learning of Complex Melodies

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[To the students of the Georgia Institute of Technology]

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ABSTRACT

The phenomenon of acquiring motor skills without active attention is termed Passive Haptic Learning. This concept of learning is applied to acquiring piano melodies through vibration on each finger while users are given a 30-minute GRE test. Mobile Music Touch (MMT) is a lightweight, wireless, haptic music instruction system consisting of fingerless gloves and a Bluetooth-enabled mobile computing device. Passages to be learned are loaded onto the software on the computer and are communicated to the MMT system through Bluetooth and are played repeatedly. As each note of the music plays, vibrators on each finger in the gloves activate, indicating which finger is used to play each note. Such passive learning is complemented with an initial controlled active learning on the piano. This study present a 12-subject pilot and a 24 subject full study for measuring the efficacy of the system for retaining simple piano melodies in without active attention. The full study is currently under progress. This paper highlights significant improvement in learning curve for the conditions involving Passive Haptic Learning. The learning afforded by PHL for a compelling and fun treatment (playing piano) will help tetraplegic patients maintain interest in the system's rehabilitative capabilities.

CHAPTER ONE

INTRODUCTION

Music is considered a recreational activity with multiple health benefits such as stress relief, mental IQ development, and an overall sense of enjoyment [7, 8]. Playing musical instruments, however, is a time-consuming activity requiring the active attention of the hands accompanied with thorough, active practice. Although time-consuming and often considered boring, practice is an integral part of the music learning process. Piano students working to improve technique often practice the same passage repeatedly to achieve accuracy, increase speed, or perfect interpretive nuance; in other words, practice helps retain and reinforce required knowledge.

This study focuses on the practice needed to play piano. Repetitive stress injuries such as tendonitis and carpal tunnel syndrome [9] are prevalent among professionals as well as amateur piano players. The majority of such injuries are not permanent but can be uncomfortable and inconvenient, often leading to periods of disuse that can significantly affect the learning process. This interruption could potentially mean relearning forgotten knowledge, increasing the amount of practice needed and thereby perhaps increasing the risk of further injuries. If the requisites and risk for learning piano can be reduced, it would make the learning process considerably more attractive to potential piano players.

Passive learning requires less effort than traditional active learning. It can be described as the learning that is “caught, rather than taught” and is “typically effortless, responsive to animated stimuli, amenable to artificial aid to relaxation, and characterized by an absence of resistance to what is learned [1].” When playing a musical instrument, movements are naturally paired with direct auditory feedback. This phenomenon of acquiring motor skills without active attention is termed as Passive Haptic Learning

(PHL). PHL when applied to musical training can establish a multimodal functional mapping that links what we hear and what we play [10].

An example of a project that utilizes the PHL concept is Mobile Music Touch (MMT), a lightweight, wireless, haptic music instruction system consisting of fingerless gloves and mobile Bluetooth-enabled computing device [2].

Haptic learning is not a new concept and has been researched before. Research has shown that a multi-modal combination of audio and haptic cues gives the user a richer understanding of musical structure and improves performance of the musical piece [14].However, MMT is novel in its ability to teach music without requiring active practice. Related work explored the use of active attention in learning. Active haptic learning is effective but may not be desired by busy or injured piano learners. The two active haptic learning systems explained in this paper are “active haptic guidance” and“active haptic feedback.” The first category talks about forced movement of hands or fingers in music learning while the second talks about the effect of kinesthetic feedback in accomplishing a task.

Figure 1.An image of the glove consisting of the shell and the hardware.

FielDrum, Haptic Guidance system, MaGKeyS and Concert Hands, are some examples of the Active haptic guidance concept, which are discussed below.

FielDrum and Haptic Guidance System utilize the "learning by feel" approach, in other words, haptic-based learning on drums [4]. FielDrum uses a combination of permanent magnets and electromagnets to guide a player's drumstick top through the motions involved in the performance of music rhythms. Haptic Guidance System uses a servo motor and optical encoder pairing to provide precise measurement and playback of motion. The study proved to be effective, producing a 17% reduction in note velocity recall error and an 18% reduction in timing recall error when compared to audio training alone. This experiment does provide evidence to validate the concept of haptic learning. However, these systems required active attention and movement of the hands which might not be possible for tetraplegic patients, who have lost significant sensation and movement in their fingers and hands. In contrast, MMT exploits passive learning and does not use forced movement of the fingers.

The Magnetic Guidance Keyboard System (MaGKeyS) embodies a new haptic guidance technology designed to facilitate sensorimotor training and rehabilitation. MaGKeyS works by employing active magnetic force to guide finger-pressing movements during sensorimotor learning that involves sequential key presses, such as playing the piano. By combining this haptic guidance with an audiovisual learning paradigm, MaGKeys created a core technology with possible applications to diverse fields such as musical training, physical rehabilitation, and scientific investigation of sensorimotor learning [5]. Instead of forced movement, MMT uses passive vibration and does not require active attention. Concert Hands is a commercial product for learning piano, electronic keyboard or single keyboard organ [11]. The system consists of two wrist pilots that guide hands to each area of the keyboard and finger sleeves that lightly signal each finger when to press the piano keys. The fingers are guided down to each piano key at the correct moment. Muscle memory is developed through active haptic practice. In addition to haptic and audio cues, the system software displays the colored finger boxes matched with the correct piano key. All the examples shown above utilize active learning which requires more attention and effort on the part of the learner. Similar to MaGKeyS, Concert Hands uses forced movement. Whereas MMT is trying to remove the active attention requirement to induce learning during inactivity of practice.

The second category focuses on non-music related kinesthetic feedback and active participation by the user. When haptic feedback is available during the exploration of 3-dimensional objects, studies have shown that individuals develop more 3-dimensional understanding than when only visual feedback is available [13]. Virtual reality training makes extensive use of advanced computer graphics. The VBB system explores audio feedback, but none provide haptic cues to the user. When a task involves the manual manipulation of objects, the need for haptic feedback becomes evident. In order for virtual reality to better approximate reality for manual tasks, the sense of touch and kinesthesia must be addressed.

One such project is Virtual Building Block.Virtual Building Block (VBB) simulation emulates the real task of building a LEGO biplane model in a virtual environment, including haptic feedback [12]. The VBB system consists of an Excalibur Force display, with three degree-of-freedom Cartesian manipulator and virtual environment software, for a 3-D graphical representation of the scene. The system generates forces to emulate selecting and placing tasks of assembling the biplane model. A study was done to assess the influence of haptic feedback on the efficacy of virtual reality training. Analysis of completion times for the real task reveals that subjects trained with force feedback performed significantly better than those who received no training. VBB system explores the feasibility of haptics in motor-skill training only but the effects of haptics on memory were not assessed.

Projects mentioned above discussed the use of haptics in learning but none explored passive haptic learning. There have been studies done by our lab on passive haptic learning using the MMT system which established that the user can passively acquire learning when exposed to repetitive practice of haptic skills for short melodies while actively paying attention to a different task. The study involved an active learning session where the subjects were given audio-visual-tactile cues on the piano and were asked to replay the melody. The best (lowest) error score was recorded using the Dynamic Time Warping algorithm, explained later. The MMT system was strapped on a subject's right hand with/without audio feedback. The glove provided appropriate vibration stimulations while the subject took a computer based GRE test for a 30 minutes duration. The user was asked the replay the song on the piano from which the final error score is again recorded. A positive difference in the two recorded error scores signifies improvement. Each participant experienced two conditions using two short randomly generated songs of equal difficulty and length. Subjects experiencing the condition involving finger vibrations accompanied with audio showed an average error improvement of 3.88 ($p<0.0001$) over the control condition of just audio. It should be noted that the participating users had little to no prior music experience. The difference in mean improvement in rhythm scores between the two conditions did not show statistical significance [2].

However, the songs chosen for the study amusical, randomly generated at a beginner level difficulty, and did not exceed a length of 10 notes. The paper did not address the effectiveness of PHL for a longer active-learning session and of longer, musical songs. It would be interesting to compare the vibration only and the vibration and music condition, since the audio might be acting as a distraction. This paper tries to address some more variables with were missing in the first paper. The two studies demonstrated in this paper have been jointly worked on by Tanya Markow and Abhishek Jain under the guidance of Dr. Thad Starner.

CHAPTER TWO

SYSTEM COMPONENTS

The Mobile Music Touch system is composed of two parts: a right-handed, fingerless glove that communicates with the computer through Bluetooth technology. The melodies are sent to the micro-controller of the glove using the MMT computer software. The glove is equipped with small vibration motors (Precision Microdrives model #310-101), one per finger; a Sena Bluetooth-to-serial module to receive commands from a controlling computer or smart phone; and an ATMega8 micro-controller for control. Workout gloves are used that were modified for tetraplegic users. The golf style glove design received “satisfied” to “very satisfactory” reviews with respect to comfort, fit, and grip [6]. The system is powered by a standard digital camera battery. Every 60 seconds the gloves repeat the melody. As each note of the music plays, vibrators on each finger in the gloves activate, indicating which finger is used to play each note.

The software used for the performance capture system has been coded on the Microsoft Visual Studio platform and is written as a mobile application. The software is capable of playing audio and MIDI files through a Casio keyboard and also capturing the note sequence performed by the user.

CHAPTER THREE

PASSIVE HAPTIC LEARNING PILOT STUDY

To measure the effects of haptic and audio stimuli on the ability of subjects to retain note sequences during a PHL session, we used a 2x2 Latin-square within-subjects study design. The two variables are stimulus method and song selection. The two songs for this study were the 45 note “dashing through the snow” selection of “Jingle Bells”, and a 44 note passage from “Amazing Grace.” Even though the two songs are of similar difficulty, rated as Level B in the Song Book that accompanied the Casio electric piano used for the study [15], they do not guarantee the same learning effort, hence song selection is an independent variable in study design. Similar to the previous study, the participants played these songs using only the right hand.

Participants were trained to play songs by having them watch the LEDs on the electric piano keyboard light corresponding to the key to press, and feel the vibration in the appropriate finger. The participants then attempted to repeat the song without any cues (no music, no LEDs, and no vibration; just play from memory). This process was repeated until the participants were able to play the song correctly without making errors. During the 30 minute PHL phase, the participant completed a paper-based GRE verbal test.

While executing this task, the participants felt the song being “played” on the glove with vibration tapping each finger that would be played in sequence. We refer to this condition as the “vibration only” condition. The other condition also involves vibration but is accompanied with synchronized music playing through the headphones; the condition is termed as “vibration with music” condition.

At the end of the distracter test period, the participant was asked to play the song passage without any cues. They were given three attempts. For each attempt, we collected an error score (number of errors made in the passage), as well as a rhythm score. We employed a “dynamic time warping” algorithm to determine these values [2].

Table 1. Passive Haptic Learning Study Raw Data

Subj	V Song	Err 1	Err 2	Err 3	V+M Song	Err 1	Err 2	Err 3
1	Jingle Bells	3	1	0	Amazing Grace	3	5	0
2	Amazing Grace	2	5	2	Jingle Bells	2	2	1
3	Amazing Grace	1	0	1	Jingle Bells	3	0	2
4	Jingle Bells	0	0	0	Amazing Grace	0	0	0
5	Jingle Bells	1	0	0	Amazing Grace	0	0	0
6	Amazing Grace	2	1	0	Jingle Bells	2	2	1
7	Amazing Grace	0	1	0	Jingle Bells	1	1	0
8	Jingle Bells	0	0	0	Amazing Grace	0	0	2
9	Jingle Bells	8	0	1	Amazing Grace	12	1	2
10	Amazing Grace	5	1	0	Jingle Bells	4	0	2
11	Amazing Grace	3	1	1	Jingle Bells	0	0	0
12	Jingle Bells	0	3	0	Amazing Grace	0	0	1
Avg		2.08	1.08	0.42		2.25	0.92	0.92

Using a paired t-test, we compared the lowest error of the vibration only condition with the vibration with music condition. We found that there was no statistically significant difference between the numbers of errors made after the distracter task for each of the two conditions (p=0.063). This is a good indicator that the vibration only condition may provide learning benefits equivalent to the vibration with music condition. This is key because it may allow piano learners to use vibration only, enabling us to remove the potential annoyance of listening to a song repeatedly for several hours a day. We also had to consider the possibility that no learning was taking place; we need to conduct a full study, considering more conditions.

In order to avoid possible cultural bias caused by song selection and familiarity, we will use newly generated tunes in our next Passive Haptic Learning study using online Wolfram Tones software [16]. In this follow-on study, we will explore all four conditions: a control, music only, vibration only and vibration with music. We seek to determine the possible contribution to learning and retention of each of these conditions.

CHAPTER FOUR

FULL PASSIVE HAPTIC LEARNING STUDY

The pilot study helped highlight a few short-comings such as song selection bias and the exclusion of a learning neutral control condition such as a audio-only condition. For this study we decided to ensure internal validity by generating our own songs. We sought phrases that would still be perceived as “musical” passages. We also desired to eliminate lateral hand motion required by many existing tunes. We constrained the generation to match up the five fingers of the right hand to five keys on the piano; they are mapped as seen in Fig. 2.

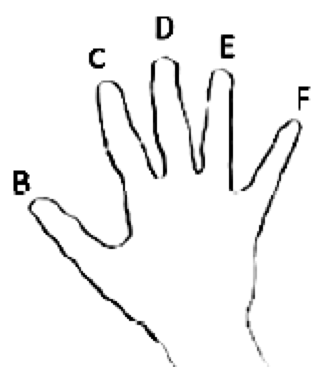

Figure 2**.** Hand Note Mapping

A quick short pilot study was conducted to assess the correct length for the song phrases. The new phrases we created were novel, not known, and were consequently more difficult to learn. These new phrases also did not have any repetition, another difference from the pilot songs of “Amazing Grace” and “Jingle Bells.” We decided to use shorter phrases, making them 22 notes in length. The four passages we generated are shown in Figs. 3-6.

Figure 3. Random Song A

Figure 4. Random Song B

Figure 5. Random Song C

Figure 6. Random Song D

The design was a modified Latin-square with four different song passages and four separate conditions. Each participant attended four one hour sessions, none of which were conducted consecutively in order to avoid fatigue. The sessions proceeded as follows:

Prior to the first session, we had the participants complete a pre-questionnaire to record the amount and type of musical training they already had going into the study. The participant put on the MMT glove; the investigator played the entire passage one time through in its entirety, allowing the participant to hear the tune, feel the vibration and see the LEDs light up in the correct sequence on the piano keyboard. Next, each phrase was played using the MMT software for the participant (with vibration through the glove, LEDs light up on keyboard, and audio playing). The participant then attempted to repeat it without assistance, from memory. Initially, we conducted this experiment as the pilot; the participant was given the chance to repeat this learning process over and over for each phrase and compound phrase until he played that phrase perfectly; only then did we move on to the next phrase or combination in the study design. However, because we had chosen to shorten the phrases, we observed that most participants reached a ceiling effect, memorizing the songs and then not forgetting them at all during the 30 minute period. In an effort to combat this effect, we chose to limit participants to a finite number of attempts for each phrase. The evolution of this study design is depicted in Table 2.

Table 2. Passive Haptic Learning Evolution Design

Passage Title	Number of Repetitions		
	Initial Design	Interim Design	Final Design
Phrase 1	Unit Perfect	1	1
Phrase 2	Unit Perfect	1	1
Phrase 3	Unit Perfect	1	1
Phrase 4	Unit Perfect	1	1
Phrase 1 and 2	Unit Perfect	4	5
Phrase 3 and 4	Unit Perfect	4	5
Phrases 1-4	Unit Perfect	8	10

The last error score for the practice session was used as the "pre-best" error score for comparison. The participant then took a quantitative GRE for a 30-minute period. Four different GRE tests were used and were given by computer, ensuring the participant received different questions each session. During this 30-minute period, the participant experienced one of the four conditions: nothing (control), audio only, vibration only, or vibration and audio. In the three non-control conditions, the audio and/or vibration repeated continuously during the period. Then, when the GRE period was complete, the participant was asked to play the passage three times without any assistance. We used a MIDI keyboard to record the participant's performance. The participant then completed a post experiment questionnaire and a NASA TLX assessment.

Each participant's performances were evaluated using the Dynamic Time Warping (DTW) Algorithm used and described in the previous study of Huang et al. [1], which allowed us to compare musical passages that differ in speed or timing. We used the DTW Algorithm twice on each passage; once to account for errors in note sequences and the second time for variances in rhythm. It accounts for errors of substitution, insertion, and deletion. DTW evaluates the costs associated with various types of errors, attempts to minimize the costs, while finding the optimal match between two sequences. The set of costs are:

1. cost of a mismatch ($cost_m$)
2. cost of introducing a gap in the first sequence ($cost_{gap1}$)
3. cost of introducing a gap in the second sequence ($cost_{gap2}$).

As in the study by Huang et al., we considered each potential type of error as equal and for this analysis assigned them a value of 1 [2].

In an example comparison of sequences used in this study:

Correct Sequence: C D E F FF B C C D E F - F FF E F - F - E C D - F D F

Actual Performance: C D E - F F B C C D E F - F B F E F - F B E C D - F D F

In the above example, the top line is the original passage, as it would be played correctly (and, in this case, we used the actual passage D). The second line is an example of an attempted performance of the passage. We can see that the participant's error score for this performance would be 3. The participant deleted an F, substituted a B for an F, and inserted a B where no note should have been played.

CHAPTER FIVE

RESULTS

We found that the four conditions: control, audio, vibration and audio+vibration had distinct error difference average values. To determine the contribution of each condition, we took the difference of the best error score before the 30-minute GRE test, and the best post-GRE error score. As was expected, the control condition resulted in the highest increase in the number of errors the participants made, with an average increase in errors of 1.25; followed by audio only, 0.81; then audio+vibration, 0.31; and finally vibration only, with, 0.19; raw data may be found in Table 3. Currently only 16 participants have been recruited and the study is still under progress. No difference among GRE scores was observed.

Note that a smaller or negative change is good here, as that indicates fewer errors being made after the GRE test period than before. For example, a participant might make 5 errors before the GRE and then only make 3 errors after the vibration only intervention, which may indicate that the intervention is aiding in learning or the retention of learning. This study is continuing as of this writing. However, the trends we are observing show that the three conditions of audio, vibration, and audio+vibration all help reduce the difference in number of errors after the GRE period. Vibration alone continues to provide the greatest reduction in errors. So far, these trends support that using vibration alone should be acceptable for piano learners. Eliminating the need for participants to listen to the song in a loop while performing their daily activities will be less distracting and make the use of MMT more tolerable and welcome in daily life.

Table 3. Passive Haptic Learning Full Study Raw Data

Trial				
	Control	Audio	Vibration	Audio+Vibration
1	4	-1	0	1
2	1	1	1	-1
3	3	0	1	-3
4	2	-1	-1	0
5	0	0	0	0
6	2	0	3	4
7	1	4	-3	2
8	1	1	-4	3
9	-4	0	-1	-1
10	0	1	-1	-1
11	4	1	2	0
12	1	1	0	0
13	1	2	2	1
14	2	4	0	1
15	1	-2	6	-1
16	1	2	-2	-1
Average Error Difference	1.25	0.81	0.19	0.31

CHAPTER SIX

FUTURE WORK

We plan to conduct a 16 person complex-melody study. This study will assess passive haptic learning in a real world environment. It is important to prove the efficacy of this study for longer and complex songs as 20 note simple songs are too easy to learn through the effort of using a glove. The complex melody PHL study will follow the same procedure as the one used for the two studies highlighted in this paper but instead of a 30 minute GRE test, we will require the participant to wear the glove for 4 hours while going through his daily activities. Since vibration only condition has proved to be equally, if not more, efficient that vibration and music condition, it will compared against the control condition. The songs to be used will have multi-chords (multiple simultaneous keys) and lateral hand movement (horizontal movement) of the hand.

Another direction which will be explored is the use of the glove for rehabilitation among tetraplegic patients. The music teaching ability of the glove will act a motivator for the patients while they experience vibrations for rehab purposes.

CHAPTER SEVEN

CONCLUSION

this study suggests that the concept of passive haptic learning is applicable to music learning. The vibration only condition performed better than the control condition by an average error of 1.06 with a p value of 0.063. It was interesting to note that vibration alone performed better than vibration plus music; however, statistical was not observed. The songs were of higher difficulty and length than the ones used for previous MMT studies which show the system's potential in learning even more difficult and complex songs. Active learning is always more effective than passive learning but no significant difference in GRE scores highlights the ability of the glove to be worn without mental load. This attribute makes it an attractive product for piano learners and tetraplegic patients.

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